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INSTRUCTION MANUAL

for use with the

"DUCTER"

T. M. REG. U. S. PAT. OFF.

LOW RESISTANCE OHMMETER

NEW ADDRESS
JAMES G. BIDDLE CO.
TOWNSHIP LINE AND JOLLY ROADS
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Third Edition

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ELECTRICAL AND SCIENTIFIC INSTRUMENTS

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737
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Table I

"DUCTER" LOW RESISTANCE OHMMETERS

Ranges and Electrical Data

Cat. No.	Scale Multiplier	Ranges In Microhms*	Ranges In Ohms	Value of Each Scale Division In Microhms	Value of Each Scale Division In Ohms	Nominal Pwr. Supply Volts	Nominal Testing Amps.	Potential Circuit Ohms†	Max. Current Lead Ohms‡
713 (Scale—0 to 100 Microhms)	10 000	1 000 000	1.00	10 000	.01	1	1	50	.520
	1 000	100 000	.100	1 000	.001	1	1	5.0	.870
	100	10 000	.010 0	100	.000 1	1	1	.50	.830
	10	1 000	.001 00	10	.000 01	1	10	.50	.139
	1	100	.000 100	1	.000 001	1	100	.50	.010
714 (Scale—0 to 1000 Microhms)	1 000	1 000 000	1.00	10 000	.01	1	1	50	.520
	100	100 000	.100	1 000	.001	1	1	5.0	.870
	10	10 000	.010 0	100	.000 1	1	1	.50	.830
	1	1 000	.001 00	10	.000 01	1	10	.50	.139
718 (Scales—0 to 500 Microhms and 0 to 5 Ohms)	Inner		5.0		.1	1	0.2	25	2.570
	1 000	500 000	.50	10 000	.01	1	1	25	.440
	100	50 000	.050	1 000	.001	1	1	2.5	.720
	10	5 000	.005 0	100	.000 1	1	2	.50	.435
	1	500	.000 50	10	.000 01	1	15	.50	.093

* One Microhm = One Millionth of an Ohm.

† Including .04 ohm resistance of duplex prod leads.

‡ The resistances shown in this column are the maximum permissible total values for the two leads between the source of supply and the Instrument, plus the two current test leads between the Instrument and the resistance under test. These resistance values will reduce the test current to 50% of the nominal value when the resistance under test is at the full scale value for its range. These figures should not be used unless long, light-weight current leads are absolutely necessary. See page 12.

Table II

Cat. No.	Test and Current Supply Leads	Length in Ft.	Nominal Current Capacity Amps	Current Lead Ohms (Total of Both Leads)	Potential Lead Ohms (Total of Both Leads)
721	Single Potential Hand Spike Leads	6	—	—	.040
722	Duplex Helical Current and Potential Leads	6	15	.040	.040
723	Heavy-Duty Duplex Current and Potential Leads	6	15	.040	.040
725-TL	Current Test Leads	5	15	.008	—
737-TL	Current Test Leads	5	100	.0025	—
733-L	Power Supply to Ducter Leads	3	15	.0045	—
737-L	Power Supply to Ducter Leads	3	100	.0015	—

NOTES

Section I

INTRODUCTION

The "Ducter" Low Resistance Ohmmeter is one of the famous "Megger"* family of resistance measuring instruments, possessing the features of ruggedness, reliability, and simplicity of operation that are so characteristic of these devices. The Instrument is a direct-indicating, cross-coil true ohmmeter designed for measuring low resistances by the fall-of-potential method. It is intended primarily for field and shop use, where simplicity and speed, at commercial accuracy, are of primary importance. When properly used it is dependable to within one per cent of full scale deflection on all of its ranges. See *Accuracy,* Page 52.

Test and Connecting Leads

Suitable test leads, hand spikes and current supply connecting leads are essential. These should be purchased with the instrument. However, if made specially they must conform to resistance and current specifications given in this Manual.

Current Supply

The source of current supply for Ducter Instruments is of great importance in terms of results. It may be either a battery or a rectifier depending on test requirements and other considerations. See Sections V and VI.

The Instrument

The "Ducter" Low Resistance Ohmmeter is practically foolproof if handled wth reasonable care. It is designed to operate with the utmost simplicity, requiring no adjustments whatever, so that an unskilled person can obtain accurate results with little or no knowledge of the Instrument's principles. The following general precautions, however, should be observed:

* Trademark Reg. U. S. Patent Office.

Precautions

— Do not test any equipment while it is energized.

— Do not use more than one cell of a battery (two cells may be connected in parallel).

— Do not use cells in series.

— Be sure the battery is charged.

— Observe proper polarity when making connections.

— Use test and current supply leads offered with the Ducter instruments. If substitutes are used they must be of proper resistance and current carrying capacity.

— When using the multiply-by-1 range (0 to 100 microhms) of Cat. 713 Instrument do not use the Duplex Hand Spikes. Use separate current and potential leads. Also use the Range 1 push-button while taking readings.

— If the automatic Cut-Out on the Instrument operates, determine and correct the cause before resetting it. Do not hold the reset button down after the Cut-Out has tripped.

— Remember that in testing any highly inductive circuits such as transformer windings, the potential spikes should be removed before the tests current circuit is disconnected. This procedure will prevent abnormal induced voltages from appearing across the potential terminals of the Instrument. Such abnormal voltages may be induced across the terminals of the transformer also, when the current circuit is opened. Therefore, remove the current connections from the transformer terminals SLOWLY. It is sometimes advisable to short-circuit the terminals of other windings before removing the current connections to prevent high induced terminal voltages across these other windings, or the winding under test may be short-circuited before removing the current test leads.

— Remember that most metals to be tested change in resistance with temperature.

Section II

GENERAL DIRECTIONS

Refer to Section III for particular Instrument in use.

PREPARATION FOR TEST

1. Place the Instrument on a firm and fairly level base. Avoid large masses of iron and strong magnetic fields. It is usually desirable to set the instrument with the supply terminals to the left of the operator.

2. The pointer will have a tendency to float towards zero before the supply and test connections are made.

3. Check the range switch of the instrument to be in the OFF position.

4. Connect power supply, observing polarity marks on the "Ducter" instrument and the supply. Connect plus to plus and minus to minus. See Page 16 of this Section and Section III for capacity of supply leads. See Sections V and VI for operation of power supply.

5. If duplex hand spikes are used, connect the spade terminals of the leads, in pairs marked C and P to the respective pairs of C and P binding posts on the instrument.

6. Before making connections to the resistance under test, it is good practice to touch the current leads, or spikes, together and note the instrument pointer, which should move immediately to zero on any range of the "Ducter" instrument. See *Indication of Weak Battery,* Page 39, Section V.

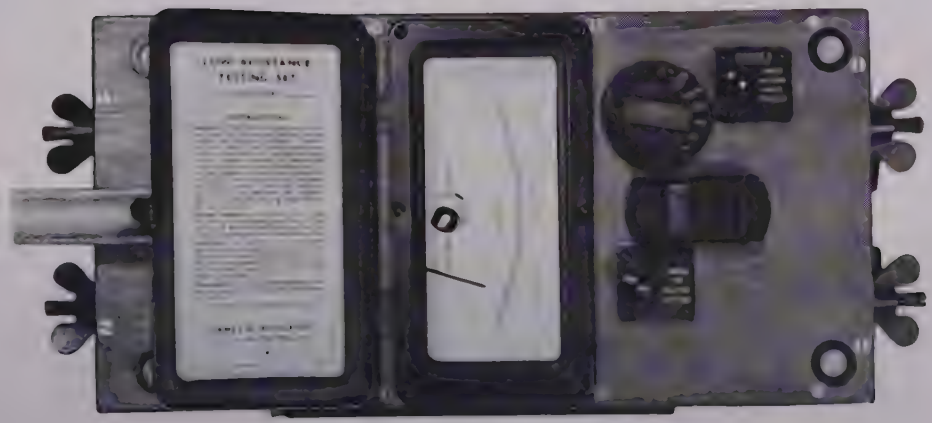
7. If the single potential hand spikes are used (which are required when using the 0 to 100 microhm range of Cat. 713 Instrument), first make suitable current connections from the C terminals to the resistance under test. Then connect the leads of the single hand spikes to the P terminals.

8. If the supply leads, or the potential leads with respect to the current leads, are reversed in polarity, the pointer will go off scale below zero when connections are made to the resistance under test.

Supply Terminals

Range Selector Switch and Scale Multipliers.

Push Button for use only on range 1 of Cat. 713 (0 to 100 microhms).



Testing Terminals

Scale. Read directly and then multiply by the Range Switch Setting.

Push Button to reset cut-out.

FIGURE 1. Top view of Cat. 713 "Ducter" Low Resistance Ohmmeter.

FACSIMILE SCALES

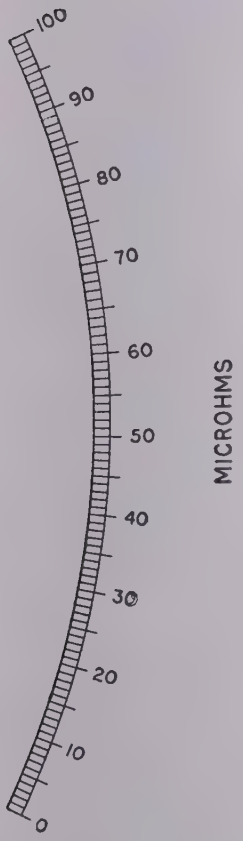


FIGURE 2. Cat. 713. Lowest range 0 to 100 microhms. Highest range 0 to 1 ohm.

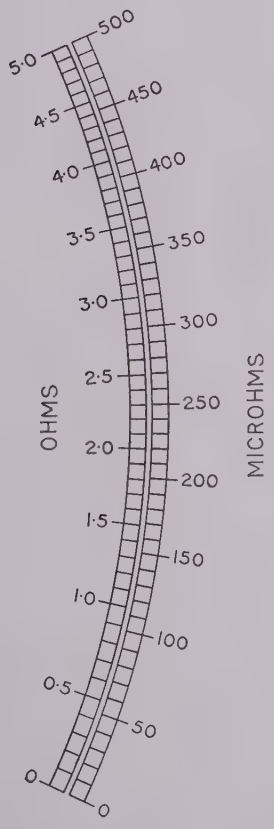


FIGURE 3. Cat. 718. Lowest range 0 to 500 microhms. Highest range 0 to 5 ohms.

Cat. 714 has same scale as Cat. 713, but graduated 0 to 1000 microhms.

MAKING A TEST

If the resistance under test is of an unknown value, start with the range switch in the highest position. If the measured value is less than 10% of the full scale deflection, move the range switch to the next position, and so on until a maximum deflection is obtained. The reading multiplied by the value of the

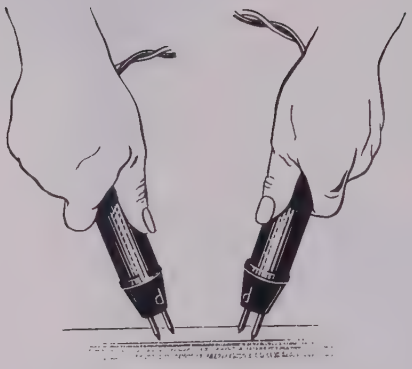


FIGURE 4. Cat. 722 Duplex Helical Hand Spikes for use with any range of "Ducter" Ohmmeter except 0 to 100 microhms. Note that the potential points marked P and P are placed towards each other.

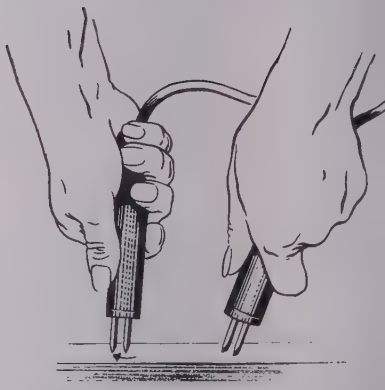


FIGURE 5. Cat. 723, Heavy Duty Duplex Fixed-Point Current and Potential Hand Spikes, for use with any range of Ducter Ohmmeter, except the lowest range (0 to 100 microhms) of Cat. 713.

range switch setting is the resistance in microhms between the potential spikes on the resistance under test. After a reading, or series of readings, it is best to return the range switch to the OFF position.

Use of Duplex Hand Spikes

Cat. 722 Duplex Helical Hand Spikes: Hold as shown in Fig. 4 with the P (potential) points towards each other. Force the handles down, causing the spikes to revolve until good contact is made. The current passes through the conductor under test from one current spike to the other, and the potential spikes must make contact with the conductor in the path of the current. The actual resistance measured is that between the points where the potential spikes are applied.

Cat. 723 Duplex Fixed-Point Hand Spikes: Hold and apply in the manner shown in Fig. 5. Good contact can be made easily by using one spike point as a pivot and rotating the other a few degrees around it. Use sufficient pressure to cut through any oxide on the surface of the resistance under test. The path of current, etc., is the same as for the helical hand spikes.

DO NOT USE EITHER TYPE OF DUPLEX HAND SPIKES FOR THE 0 TO 100 MICROHM RANGE OF CAT. 713 DUCTER INSTRUMENT.

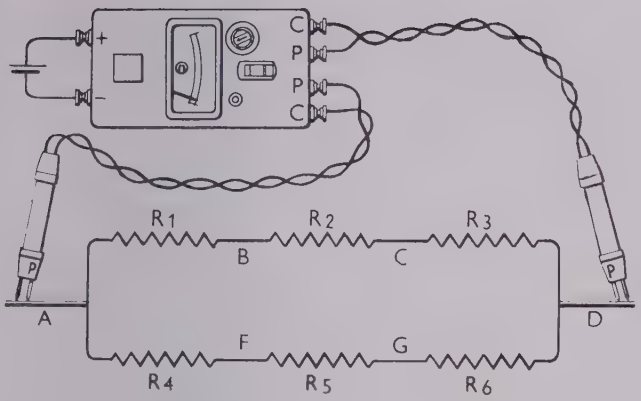


FIGURE 6. Testing resistances in parallel with Duplex handspikes.

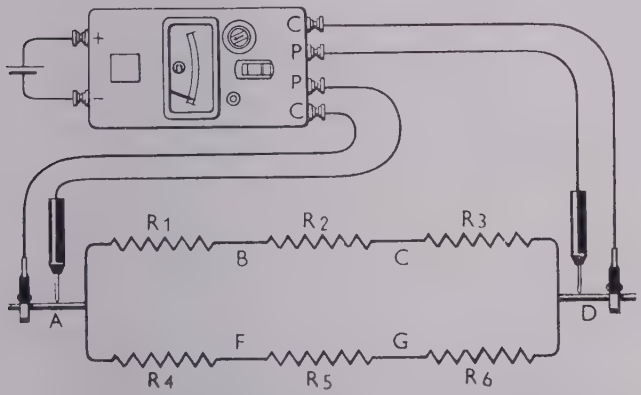


FIGURE 7. Testing resistances in parallel with single handspikes.

Testing Resistances in Parallel

With both current and potential connections connected at A and D (Figs. 6 and 7) the instrument will read the combined resistance of the two parallel circuits, e.g.,

$$R=\frac{(R_1+R_2+R_3)\times(R_4+R_5+R_6)}{(R_1+R_2+R_3)+(R_4+R_5+R_6)}$$

Testing between A and B, B and C or C and D will, however, only give a comparison of the resistance R_1, R_2, and R_3 and not the true value of each resistance.

For instance when using Duplex handspikes, a test between

B and C (Fig. 6) will give the value of resistance R_2 in parallel with resistances R_1, R_3, R_4, R_5 and R_6, and the reading will thus be less than the true value of R_2.

With the single handspikes, although the resistances R_1, R_2 and R_3 (Figs. 7 and 8) can be compared by moving the potential spikes between A and B, B and C and C and D, their true value will not be given because the whole of the testing current is not passing through the resistance under test. For instance, if the two parallel circuits are of equal resistance, only half of the battery current will pass through each circuit so that the resistance readings on the components of each circuit will have to be multiplied by two, or by three if there are three parallel circuits of equal resistance.

A few formulae for calculating the resistances of individual components of a network are given in Section VIII.

Testing Resistances in Series

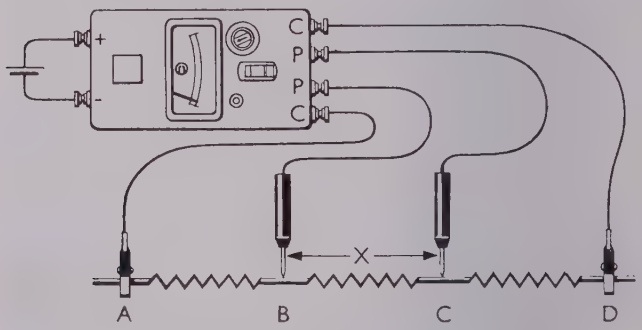


FIGURE 8. Test with single handspikes. The current leads are clamped on at A and D and the potential spikes applied to A and B, B and C, and C and D. The resistance measured is that between the potential spikes. When testing a number of resistances in series with single handspikes, it may be necessary to increase the voltage in order to obtain the required testing current.

Use of Single Hand Spikes

Cat. 721 Single Potential Hand Spikes may be used with any range of the Ducter instruments and *must* be used with the 0 to 100 microhm range of Cat. 713 instrument. In any case, separate current leads must be connected from the instrument C terminals to the resistance under test, or to points in the circuit that will permit the total testing current to flow through the resistance being measured. When the current leads are con-

nected (with power supply connected to the instrument) the instrument pointer will move to its zero position before the potential spikes have been applied.

Apply the single potential spikes across the resistance to be measured—or across any desired or available portion of it—remembering that the spike points must be in the path of the test current, the same as when using duplex hand spikes.

It is frequently desirable and more convenient to use the single hand spikes and separate current leads—especially where several separate and possibly changeable resistances are in series. One can probe with the potential spikes at various points between the current connections.

When connecting the separate current leads in preparation for using the 0 to 100 microhm range of Cat. 713 Ducter instrument, make sure the leads are of sufficiently low resistance—preferably not more than .0025 ohm—and that low resistance contacts are made to the resistance or circuit under test. See Item 2, Page 21.

In testing highly inductive circuits the potential spikes should be removed before the test current circuit is disconnected. This procedure will prevent abnormal induced voltages from appearing across the potential terminals of the instrument. See Section IV, under "Transformers and Coils."

Automatic Cut-Out

The potential circuit of the instrument is protected against excessive voltage, should the resistance under test be either open or unexpectedly high. This is accomplished by a quick-acting automatic cut-out in the current circuit as shown in Figs. 22, 23 and 24.

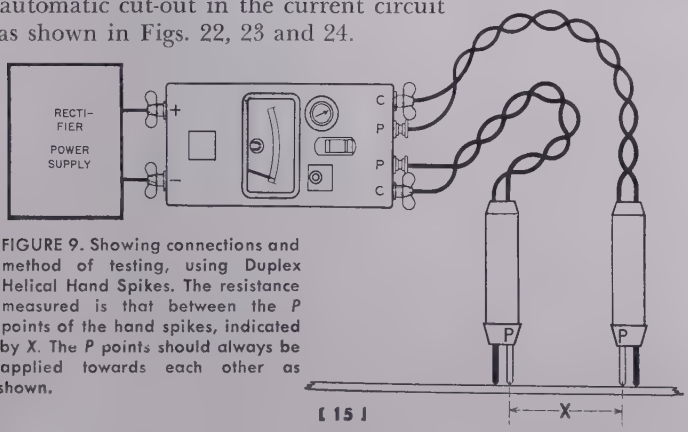


FIGURE 9. Showing connections and method of testing, using Duplex Helical Hand Spikes. The resistance measured is that between the *P* points of the hand spikes, indicated by X. The *P* points should always be applied towards each other as shown.

This cut-out is operated by polarity trip coils across the potential circuit, whenever the potential across the resistance being measured is excessive. An indicator in the scale plate shows whether the cut-out is open or closed, and a push-button for resetting it is located nearby on the top of the case. If the cut-out is open, the two points in the cut-out indicator (see Fig. 1) will be separated. Resetting the cut-out, by pushing the reset button, will also close the points of the indicator. The cut-out is a safety device, and should operate only (1) if connections are not properly made, (2) if the resistance under test is open, or (3) if the range switch is on too low a setting. Warning: If the cut-out has tripped, do not hold down the reset push-button. Investigate the cause and correct the reason for the cut-out operation before resetting it.

Current Leads

The resistance of the current test leads and their contacts with the resistance under test are not included in the measurement, and therefore introduce no error unless these resistances are excessive.

If one uses the test leads and the power supply connecting leads that are offered with the Ducter instruments and power supplies, there should be no trouble due either to current or to potential lead resistances.

Current Lead Resistances

Should it be necessary to use leads other than those offered, make sure that the combined resistance of the power supply and current test leads does not exceed the figure given in the last column in Table I, Page 4, for the particular range being used.

Use of Long Leads

Where it is absolutely necessary to use current supply and/or testing leads of greater length than those regularly offered with the Ducter equipment, and assuming that one can make up and measure his own leads, the figures in the last column in Table I, Page 4 will serve as a guide.

The conductor resistance between the supply, and through the instrument, to the resistance under test may be such that the rated test current is reduced by as much as 50% without affecting accuracy *on this account* by more than about 1%. The

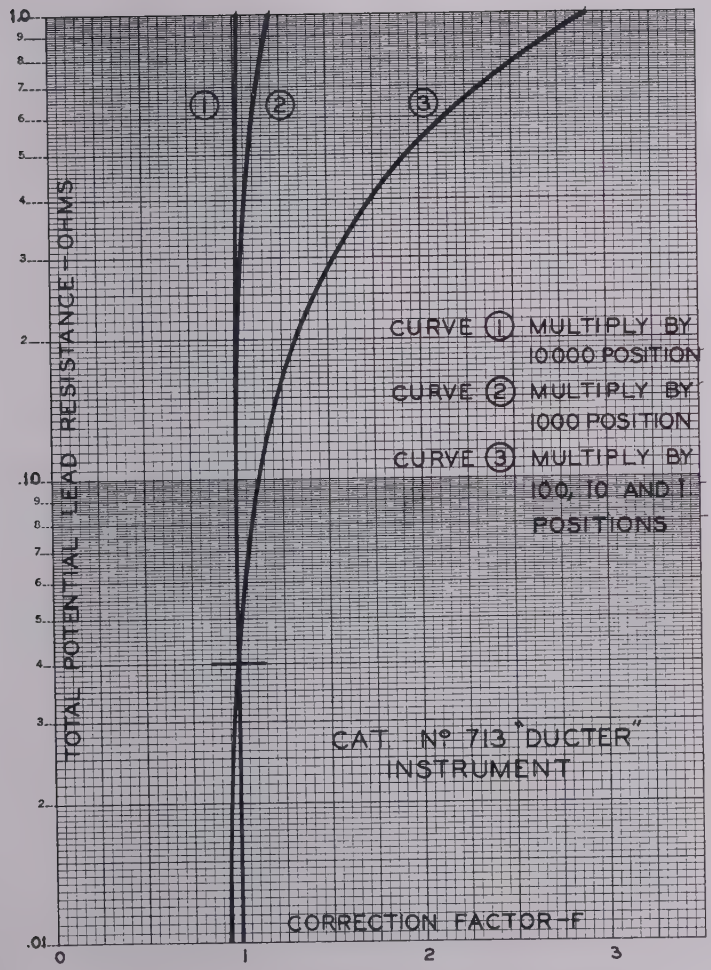


FIGURE 10. Curves showing correction factor to be used as multipliers for readings obtained with Cat. 713 "Ducter" Instrument, using potential leads having a total resistance different from .04 ohm.

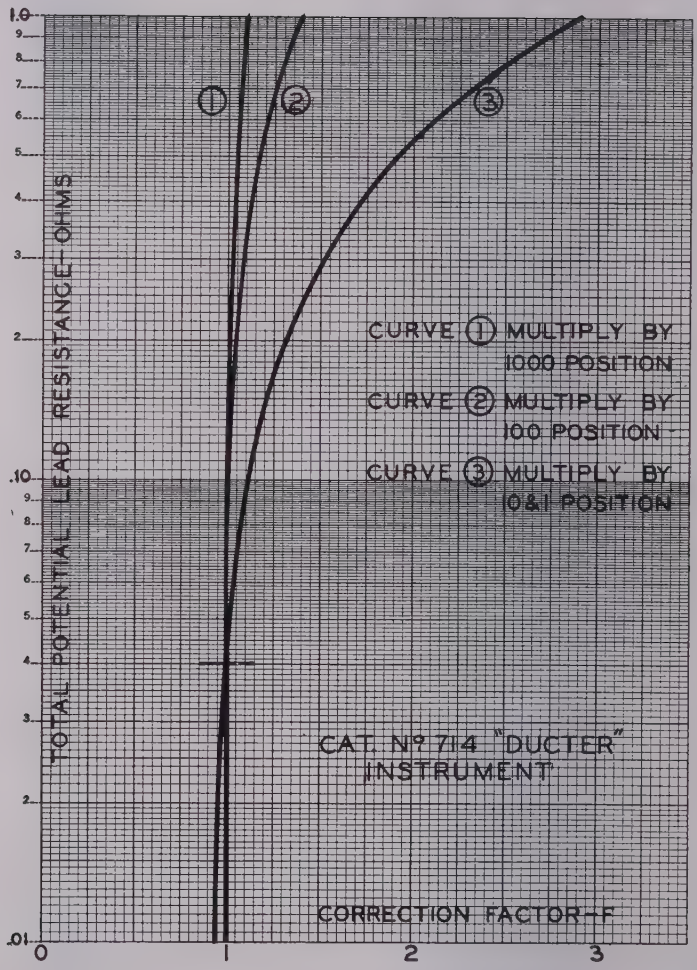


FIGURE 11. Curves showing correction factors to be used as multipliers for readings obtained with Cat. 714 "Ducter" Instrument, using potential leads having a total resistance different from .04 ohm.

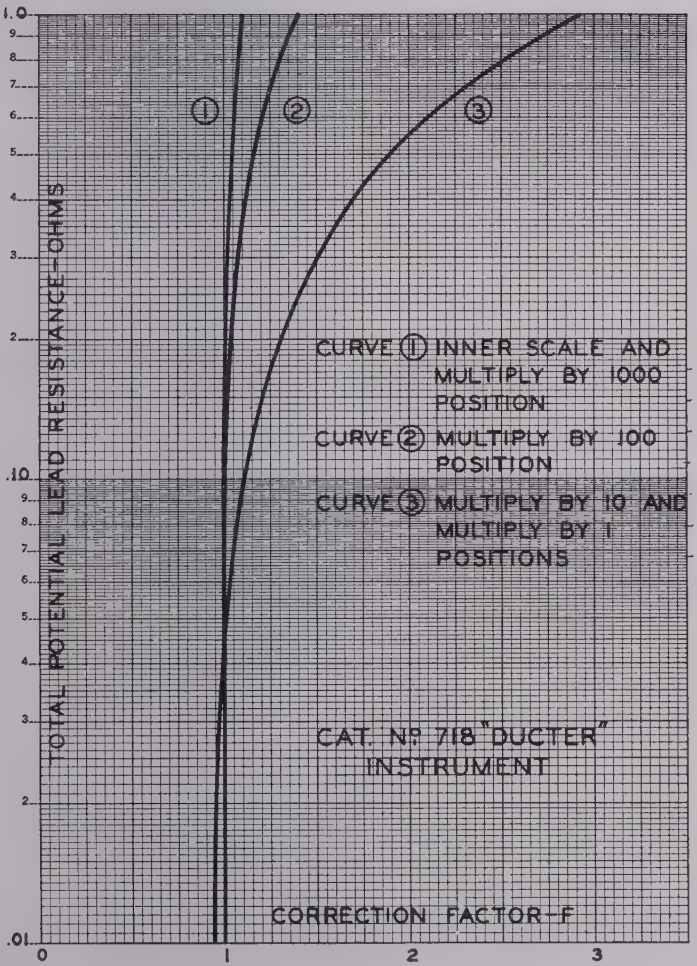


FIGURE 12. Curves showing correction factors to be used as multipliers for readings obtained with Cat. 718 "Ducter" Instrument, using potential leads having a total resistance different from .04 ohm.

effect on sensitivity is negligible for a reduction in current up to that value. This means that the total resistance of the current conductors from the source of supply to the instrument, and from the instrument to the resistance under test, should not exceed the values given in Table I on page 4, if the accuracy is not to be affected by more than about 1% beyond the normal 1% accuracy of the instrument. In general, it is strongly recommended that current leads be used having total resistances well below these values.

Potential Leads

The potential leads, regularly supplied with the "Ducter" single or duplex hand spikes, each have a resistance of .02 ohm at 20° C. (68° F.) (or .04 for the two leads) and the Instrument is calibrated accordingly. Therefore, if other potential leads are used, they should have a total resistance of .04 ohm. If extra long and light potential leads are required, necessitating a total potential lead resistance in excess of .04 ohm, then a correction factor must be applied to the Instrument readings if accurate results are desired. Curves in Figs. 10, 11 and 12 show the necessary correction factors for potential leads having various total resistances.

These curves are based on the following expression:

$$F = \frac{R - R_C + R_L}{R}$$

Where: F = Correction Factor

R = Potential circuit resistance of Ducter Instrument, including R_c (See Table I)

R_C = .04 ohms = compensation for potential leads in calibrating the instrument

R_L = Actual resistance of potential leads in use.

Section III

DIRECTIONS FOR SPECIFIC RANGES OF "DUCTER" INSTRUMENTS

Cat. 713—All ranges except 0 to 100 microhms

Cat. 714—All ranges

Cat. 718—All ranges

No instructions beyond those given in Section II are required for the operation of these ranges.

The duplex helical and fixed-point hand spikes and leads are intended for all ranges—except 0 to 100 microhms. Table I, Page 4, gives electrical data, and Sections V and VI cover appropriate battery and rectifier power supplies.

Cat. 713, 0 to 100 Microhm Range

Referring to Section I, page 8, it will be noted that the 100 microhm (multiply-by-1) range of this instrument requires nominally 100 amperes through the resistance under test. This is necessary in order to obtain the extreme sensitivity of this range, permitting resistance values as low as .000001 ohm (1 microhm) to be measured.

Because of the relatively high current used for this range, several points in addition to those listed in Section II, page 9, must be considered in the use of the Cat. 713 instrument as follows:

1. The power supply must be of ample capacity to deliver up to 100 amperes without an appreciable voltage drop. See Sections V and VI.

2. The connecting leads from the source of supply, together with the current leads between the Instrument and resistance under test, must be of ample current carrying capacity to deliver 100 amperes without undue heating or excessive voltage drop. The total resistance of the conductors used for both the

current supply and the current test leads should not exceed about .005 ohm. A total resistance of as much as .010 ohm may impair the accuracy of the indications beyond the normal 1% accuracy of the instrument.

If possible, use the two pair of leads offered with the instrument and its power supply, viz:

Cat. 737-L, power supply to instrument, 3 feet,	.0015 ohm
Cat. 725-TL, current test leads, 5 feet,	.0025 ohm
Total current lead resistance	.0040 ohm

These leads are made of #4 AWG stranded copper.

3. Use the Cat. 721 Single Potential Hand Spikes and connect to the instrument testing terminals marked P and P. *Do not use* Cat. 722 Duplex Helical or Cat. 723 Duplex Fixed-Point Hand Spikes and Leads with the 0 to 100 microhm range.

4. In the multiply-by-one position of the range selector switch (0 to 100 microhm range) a push-button-operated switch is provided in order to avoid unnecessary drain on the battery or heating of the power supply when using this range. This switch is in the main current circuit of the instrument only when the selector switch is in the multiply-by-1 position, and must be depressed manually in order to obtain a reading.

Do not attempt to use this push-button for other ranges.

Procedure

The following is the procedure for using a 100-ampere battery or rectifier power supply and for operating on the 0 to 100 microhm range.

First, make low resistance connections between the Ducter and the apparatus under test, and between the + and — terminals of the Ducter and the power supply (battery or rectifier). If using a rectifier connect supply cord to 115 volts, 60 cps (see Section VI). Also see directions on rectifier unit.

Next, have the potential hand spikes connected and ready for application.

When using a Battery Kit, the Range 1 push-button on the Cat. 713 Ducter instrument serves to energize and de-energize the circuit, including the instrument and the apparatus under test. No separate switch is necessary, but the push-button must

be held down manually for the duration of the test and, in the case of inductive circuits, until *after* the potential hand spikes have been removed.

When using a 100-Ampere Rectifier: First, depress the Range 1 push-button on the Ducter, and while holding it down, depress momentarily the 100-ampere push-button on the rectifier. This closes and latches the high-rating (100-ampere) relay in the rectifier, and if connections have been made properly, the ammeter will indicate that nominal test current of about 100 amperes is flowing through the instrument and the resistance under test. Remember that all current connections between the rectifier, Ducter and resistance under test must be complete to permit the relay to latch.

While this current is flowing (and while holding down the Range 1 push-button), have an assistant apply the potential hand spikes at desired points across the resistance being measured.

Read the position of the pointer over the Ducter scale.

Remove the potential hand spikes, and release push-button.

If for any reason the current circuit is opened, the 100-ampere relay in the rectifier will automatically unlatch and return the rectifier to the 10-ampere output rating. In this event, continuity in the current circuit must be re-established, and the 100-ampere push-button on the rectifier again depressed momentarily to restore the 100-ampere output.

Removing Potential Hand Spikes

If the resistance under test is a circuit of high inductance it is important that the single potential hand spikes be removed from the circuit before the push-button on the Ducter instrument is released. Unless this is done a high induced voltage may appear across the P terminals of the Ducter instrument.

NOTES

Section IV

COMMENTS ON CERTAIN TYPES OF EQUIPMENT TO BE TESTED

CABLE AND CONDUCTOR JOINTS

High-resistance joints in cables and conductors are a major source of trouble in electrical circuits, and one of the chief uses of the "Ducter" Low Resistance Ohmmeter is in combatting such conditions. High-resistance joints cause objectionable voltage drops, loss of power, and damage from localized heating. A few mental excursions into Ohm's Law will reveal the fact that a small fraction of an ohm in high-current circuits can equal an appreciable number of volts, and will result in lost kilowatts. Circuits normally having low resistances, say in the order of 11,000 microhms (.011 ohm), which is equivalent to about 1,000 feet of 1,000 mcm cable, could easily have defective joints that would double that value. If this cable is rated at 370 amp., the voltage drop would be 100% above normal, or a total of 8 volts, and would waste 36 kwhrs per 24-hour day above the normal loss.

Such defective joints can be discovered by evidences of heat, or by measuring the voltage drop during normal load periods. These methods are not as simple as measuring the cold resistance of the joints, either when they are installed or during off-load periods. Any well-made joint should have a resistance between the points measured not greater than the same length of the cable or conductor involved. This would mean, in the case of the 1,000 mcm cable previously mentioned, that any joint in its length within a space of one foot should not exceed 11 microhms (.000011 ohm). The "Ducter" Low Resistance Ohmmeter measures values down to 1 microhm (.000001 ohm).

Useful Formulas

The foregoing value of 11 microhms is determined as follows: $R = \rho \frac{l}{a}$ where $\rho = 10.7$ ohms/cm.ft. at 20° for 97% conductivity copper. l = length in feet, a = area in circular mils.

$$R = \frac{10.7 \times 1}{1{,}000{,}000} = .0000107 = 10.7 \text{ microhms.}$$

This calculation is given here for convenience so that users may be reminded of the method of determining the resistance of any conductor. The following formulas will also be helpful.

Rectangular or square-shaped conductors:

$$\text{Circular mils} = \text{cm} = \frac{\text{sq. mils}}{.7854} = \frac{\text{in.}^2 \times 10^6}{.7854}$$

For round conductors:

$$\text{Circular mils} = \text{cm} = (\text{dia. in mils})^2$$

What Makes a Good Connection

In making low-resistance connections or joints in electrical conductors, the cleanliness of the contact surfaces cannot be over-emphasized. It can be demonstrated that the thinnest film of oxidation or corrosion can affect the resistance of the joint greatly. Furthermore, the electrical resistance of an unfused metallic joint is a function of contact area and pressure, as well as cleanliness. In the case of fused joints the resistance is controlled by the area and effectiveness of the bond. The "Ducter" Low Resistance Ohmmeter is used widely in controlling these variables.

In the discussion of conductor joints it can be mentioned that the "Ducter" Instrument is also used to a great extent in checking the resistance of metallic conduit and structural joints, in those cases where the conduit or steel work is used as a conductor in returning current to the neutral of the source of supply.

To Measure Resistance of Long Conductors

Occasions arise where it is desirable to determine the average copper temperature of cables or conductors, or to measure the resistance of each conductor in a circuit as a check on the condition of inaccessible joints. In such cases it is usually imprac-

tical to measure the resistance between the terminals of the circuit because of the distances involved.

The alternative of course is to tie two conductors of the circuit together at the far end, and measure the resistance of the two in series. This allows the average resistance of the two conductors to be determined. If the circuit is a single conductor one having a ground or rail return, then the only alternative is to use a conductor of an adjacent circuit for the test. In that event, the resistance of the conductor used to complete the circuit for test purposes must be known for some particular temperature beforehand if reliable results are to be expected.

In all cases, the resistance of the temporary jumper, including its contact resistances, at the far end must be determined unless they are known to be negligible.

If three or more conductors are available in the circuit, then they may be connected together in groups of three at the far end, forming a star resistance network. By measuring the resistance of the three legs in pairs the resistance of each individual conductor can be readily calculated. See Section VIII.

OIL CIRCUIT BREAKER ASSEMBLIES

The "Ducter" Low Resistance Ohmmeter is used extensively in checking electrical contacts and joints throughout oil circuit breakers, from the top-terminal of one bushing, through the main and auxiliary contact assemblies, to the top-terminal of the associated bushing. Several joints and contacts are included in this circuit which may give trouble.

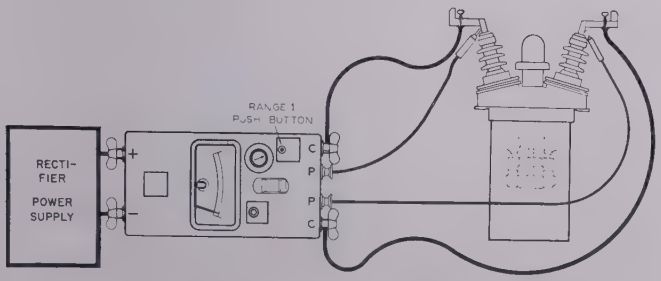


FIGURE 13. Showing connections for testing circuit breaker contacts. This figure also shows connections when using Range 1 of Cat. 713 (0 to 100 microhms). The resistance measured is that through the breaker between the potential hand spikes. These should always be placed inside the current connections.

The frequency of dropping or entering oil tanks of large oil circuit breakers for inspection and maintenance purposes is governed by operating experience, economics, the frequency of fault operations, and the ratio of the fault energy interrupted to the breaker interrupting capacity. The frequency will usually vary from every six months to every two years, depending upon local conditions. A method that will permit the maintenance engineer to feel reasonably sure that no mechanical or electrical faults exist within the tank, without exposing the parts to visual inspection, is definitely economical. The "Ducter" Low Resistance Ohmmeter provides a method for doing this by detecting abnormal resistances within the breaker when it is in the closed position.

Sources of Trouble

Numerous types of bushing top-terminals and top-terminal assemblies are to be found in service, many of which have been known to give trouble from over-heating if not properly assembled.

The center or conducting rod, or tube through the bushing itself, is usually one continuous piece attached to the top-terminal assembly by a fused or unfused mechanical joint, and the resistance of this joint will depend upon design and workmanship.

The contact assembly at the bottom of the bushing's center conductor is mechanically attached to permit ready adjustment or removal, and again the resistance of this joint will depend upon design and workmanship.

The movable-contact assembly, made up of the bridging or cross-member, main contacts, and auxiliary (arcing) contacts, has joint resistance values which vary depending upon design and assembly workmanship, aside from the actual contact resistance between the stationary and movable members.

The component parts of the bushing top-terminal assembly, together with those of the stationary and movable contact assemblies, are usually non-ferrous castings, and sometimes develop cracks as a result of misalignment or undue strain. These failures usually affect the overall resistance of the "closed breaker" total resistance and can be detected by "Ducter" Instrument measurements.

The auxiliary and main contacts themselves, both movable and stationary, oftentimes complete the electrical circuit through braided or leaved flexible bonds or jumpers which are

Table III

MAXIMUM CIRCUIT BREAKER CONTACT RESISTANCE VALUES AS ESTABLISHED WITH THE "DUCTER" LOW RESISTANCE OHMMETER

The following figures are from data contributed by various public utility companies, and are based on studies of "as found" and "as left" conditions. All measurements were made at the bushing terminals.

Circuit Breaker Type	KV.	Amps.	Max. Allowable Resistance Microhms OCB Closed
FH 6	15	600	300
FH 203	15	600	300
FH 206	15	600	200
FH 206	15	3000	30
FH 209	15	2000	50
FHB-123	15	600	300
FHB-123	15	1200	100
FK2	7.5	300	1000
FK12	15	500	200
FK-53B*	15	2000	50
FK-230-16A	15	600	300
FK-330-16A	15	600	300
FK-339-1500-2	34.5	1200	150
FK-339-1500-2	15	1200	100
FKR-132B	15	600	200
FK-339-1500	34.5	2000	50
FHK-130-20B	15	600	300
FHK-130-20B	15	1200	100
FHK-130-28B	15	3000	50
FHK-230-20B	15	600	300
FHK-230-28B	15	3000	50
FHK-330-20B	15	600	300
FHO-136-1026AS	25	400	400
FHO-136-1026AS	25	800	300
FHKO-39-32BS	37	400	600
FHKO-39-48BS	73	400	600
FHKO-39-60CY	73	1200	280
FHKO-139-24AS	15	2000	75
FHKO-139-24BS	15	800	300
FHKO-139-24BS	15	1200	200
U Deion	15	600	200
150U12	15	600	100
150U22	15	600	100
D13 B	15	600	200
D13 B*	15	600	150
D13 C	15	600	200
D17 B	15	800	250
DR 40	15	1200	100
DR 60*	15	1200	100
F 8	15	600	200
F 120	15	600	200
F040A	15	600	200
F040A	15	1200	150
F040C	34.5	600	200
02	15	600	200
02	15	1200	150
Y-1*	15	2000	50
FHKO-139-36CS	15	4000	40
FHKO-139-54CY	73	800	400
FHKO-139-60CYF73	73	1200	300
FHKO-139-114CY	187	1000	500
B-7A	15	2000	50
B-13	7.5	600	100
CO	15	600	200
CO-11	15	1200	150
CO-111	15	1200	150
E-16	15	600	150
E-16*	15	600	75
E-17	15	2000	50
G1	25	400	600
G-11	37	600	200
G-22-2	73	800	350
G-222	187	1000	350
G-222A	73	800	350
G-222S	187	1000	350
G03	15	600	200
G03B	69	600	200
G22	15	2000	50
GM 4S	138	800	400
0-241	15	600	200
0-241	25	2000	100
0-331	15	2000	75
0-331 S	25	2000	75
FHKO-239-108CY	230	1000	500

* Circuit breaker contacts are silver plated.
Any breakers that cannot be made to conform to these values should be investigated.

flexed during opening and closing operations. The fraying or breaking of the strands or leaves of these jumpers can be detected by an increase in the "closed breaker" total resistance.

The contact resistances of the main and auxiliary contacts, because of their function, are naturally the most common variables. Burning and carbonization of these contacts under arcing conditions, when allowed to become aggravated, eventually increase the contact resistance to such an extent that the heat caused by current further carbonizes the oil between the contact surfaces, thus causing a cumulative action.

Procedure

To determine the condition of the contacts by the resistance measurement method, the resistance should first be measured with the breaker fully closed. This measures the resistance of the main and auxiliary contacts in parallel.

The breaker is then unlatched and allowed to open slowly until the main contacts have parted, thus measuring the resistance of the auxiliary contacts only.

The normal resistance of circuit breaker contacts varies considerably in different types of breakers ranging from about 30 to 1,000 microhms. Referring to the figures offered in Table III, it would be helpful to have additional data for both these and other types of oil and air circuit breakers. Correspondence is solicited.

What has been said about the method of analyzing conditions in oil circuit breakers applies equally to air circuit breakers of the various types, and to a great extent, disconnecting switches, air-break switches, and knife switches.

ROTATING EQUIPMENT

One of the most common uses of the "Ducter" Low Resistance Ohmmeter is the bar-to-bar testing of d-c and commutator-type a-c armatures. These tests are made primarily for two reasons—(1) to reveal shorted commutator bars, shorts in armature coils, and shorts between equalizers or cross connections; and (2) to reveal high resistance joints between commutator bars and risers, risers and coil ends, and coil back-end connections. Of the two, the latter is the more common source of trouble.

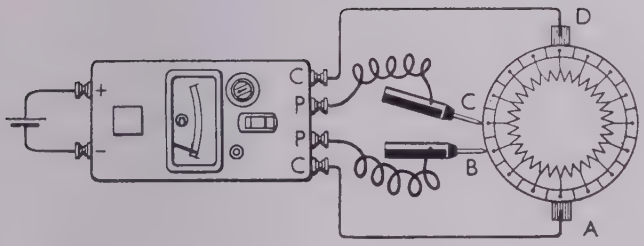


FIGURE 14. Showing test connections to a drum wound armature.

Motor Armatures

Experience has shown that periodic tests on all types of series traction motor armatures are well justified—types such as diesel-electric, crane, mill, surface and subway car, trolley coach, and MU car motors. The practice establishes the bar-to-bar resistance value of the new or correctly rewound armature, and detects any increase in riser-joint resistances resulting from overload or faulty fields.

The Duplex Hand Spikes are ideally suited for making bar-to-bar tests on all armatures, with the possible exception of extremely small commutators in the fractional horse-power class. The spikes may be applied either at the edge or the neck of the commutator, depending upon whether short circuits between bars, or high-resistance joints are to be investigated. Ordinarily, the bar-to-bar resistance of armatures will fall in the 1,000 or 10,000 microhm range of the "Ducter" Instrument.

Two Methods of Test

Either of two methods may be used in making armature measurements—one the direct comparison method, and the other the direct reading method. The direct comparison method assumes no knowledge of the resistance of the separate coils, and simply involves taking measurements between all bars and noting any marked deviation from the average. Deviations beyond 3% are worthy of investigation.

The direct-reading method involves the measurement of the actual resistance of a good spare coil to establish a definite minimum bar-to-bar value at the same or corrected temperature.

For a simplex, wave (series) winding the number of coils in series between adjacent bars will equal the number of pairs of poles.

For simplex, lap (parallel) windings the number of coils included between adjacent bars is always one, regardless of the number of poles. If either the wave or lap winding is of the double or duplex type, the circuit will be completed for testing purposes through the first and third bars rather than adjacent bars.

In the direct reading method, the Duplex Prods are usually applied at the riser end of the commutator to eliminate the resistance of the commutator bars. However, the normal individual bar resistance can be determined separately, and included with that of the separate coil to establish a minimum value. The prods would then be applied to the commutator edge, and any excess resistance over that figure would be caused by joint resistance.

Riser Joints

In investigating riser-joint resistances it is sometimes advisable to apply the prods directly across the riser joints themselves, i.e., one prod at the commutator neck and the other at the coil end. The Duplex Prod's revolving points are especially suitable for making contact through paint and varnish into the risers and coil ends. Thus it is possible to compare the resistance of joints between commutator bars and risers, or between risers and coil ends at the front end of the armature, or between backends at the rear of the armature.

Equalizers

Lap-wound armatures having equalizers or cross-connections increase the complexity of the network of parallel paths. In one method of winding equalized lap-wound armatures, the cross-connections are made behind the commutator risers; and in another method they are made at the back end of the armature coils. The pitch of the cross-connection is the number of commutator bars divided by the number of pairs of poles.

Therefore, to test the resistance of equalizers the Duplex Prods should be applied to the bars having known cross-connections, and spaced over the number of bars representing

that pitch. If the equalizers are connected at the risers the measurement will include the resistance of the equalizer jumper and its joints in parallel with the ring or jumper of the same group in the opposite direction around the armature. Armature coils are also in parallel with these circuits and will lower, to some extent, the measured resistance. If the equalizers are connected at the back end, two half-coils and their joints will be included in series with the equalizer jumper or ring section involved, unless the Duplex Prods are applied to the back end.

It is suggested that reference be made to standard textbooks* on armature practices for further information concerning networks involved in the several types of armature windings.

Other Tests

The "Ducter" Instrument is also useful in detecting abnormal or unbalanced resistances in other parts of rotating equipment, such as joints between studs and collector rings in rotary converter armatures, and wound-rotor induction motors. The resistance from brush holders, through the brush arm, to the brush-arm bracket of d-c motors and generators should be balanced to prevent an unequal division of current between brush arms and holders of the same polarity.

Series field circuits of d-c rotating equipment and a-c traction motors should be kept to normal values to prevent localized heating in joints and connections. Similarly, the salient and cylindrical-pole fields of synchronous equipment, such as condensers and alternators, may develop defective joints or shorts between turns that may cause trouble from localized heating if allowed to continue.

TRANSFORMERS AND COILS

The measurement of the winding resistances of transformers and of coils is comparable to that of any other electric circuit, with one exception. Such windings have inductive characteristics, as well as d-c resistance.

In a complete transformer, fused winding joints, tap-changer contacts, and bushing assembly joints are included in the test, and must be considered when analyzing conditions.

* See "Connecting and Testing Direct Current Machines," Annett & Roe, McGraw-Hill.

The resistances of the low-voltage windings of power transformers will ordinarily be less than one ohm, and any of the three available "Ducter" Instruments may be used in such cases. However, the resistances of the high-voltage windings of most power transformers, unless they are of large capacity, will usually exceed the 5 ohm maximum value available with the highest range Cat. 718 "Ducter" Instrument.

Circuit Time-Constant

When the d-c potential of approximately one volt is applied to a transformer winding or coil during a "Ducter" Instrument test, the length of time for the current to build up to normal, is dependent upon the time-constant of the circuit. In other words, it depends upon the resistance in ohms and the inductance in henrys of the complete test circuit, and may ordinarily require several seconds.

The time-constant T of the circuit is:

$$T = \frac{L}{R}$$

where L is the inductance of the winding in henrys, and R is the resistance of the complete series circuit in ohms. It will be noted from this expression that T is inversely proportioned to the circuit resistance, *i.e.*, the higher the resistance the shorter the time required to build up the normal test current.

The time required to reach stable conditions ordinarily adds very little to the testing time, but one should wait until the pointer of the "Ducter" Instrument comes to final rest before taking a reading. The foregoing assumes that the other transformer windings are open-circuited. If any other magnetically coupled winding or windings are short-circuited at the time the voltage is applied, then the time required to reach stable conditions will be greatly increased, the shorting of the magnetizing impedance effectively lengthening T.

Important

When dealing with inductive circuits it is of utmost importance that the test current circuit should not be allowed to become disconnected until after the reading has been taken, and *only after the potential prods have been removed.*

Large power transformers with a considerable number of turns may have appreciable inductances, and if the current test circuit is broken instantly, before the potential prods have been removed, a high voltage will appear across the *P* terminals of the Instrument.

Even after the potential prods have been removed, the current connections at the terminals of the transformer under test should be removed SLOWLY before any other point in the current test circuit is disconnected, otherwise a voltage may be produced which will be dangerous to the equipment being tested, or to the persons involved in the test activities. Furthermore, if the winding or windings not being tested are open-circuited at their terminals, a voltage in proportion to the turn-ratio of the windings will be produced at these terminals. It is often advisable to short-circuit the winding under test, or the other windings, before disconnecting the current test leads.

In the light of the foregoing it is not recommended that the Duplex handspikes be used in transformer winding tests since it may be difficult to open the potential contact first. Separate current test leads and the Single potential handspikes are, therefore, recommended for measuring the resistances of transformer windings.

NOTES

Section V

POWER SUPPLIES

Ducter Low Resistance Ohmmeters are designed to operate from a nominal one-volt d-c supply. The following may be used depending upon current requirements for the various instrument ranges (see Table I, page 4): (a) dry cells, (b) nickel-iron-alkaline cells, (c) nickel-cadmium cells, and (d) specially designed rectifiers.

Lead-acid cells are not recommended on account of their output voltage being considerably in excess of one volt, which may result in excessive current and heating in the instrument. However, lead-acid cells *may* be used if the leads between the cells and the instrument are made of such resistance that the voltage at the instrument input terminals does not exceed about 1.40 volt during test.

Battery Power Supply Kits and *Portable Rectifiers* have been specially designed for use with Ducter Ohmmeters. They provide proper current supply—in a single package—with maximum convenience and utility. A suitable selection of a Battery Kit or a Portable Rectifier will save time and trouble in the use of your instrument.

Selection of Power Supply

Table IV, page 38, shows requirements that can be met by various units. Selection between them, if not made at the time your instrument was purchased, should be considered with care before your instrument is placed in service. The most important factors are the use to which the instrument is to be put, the range or ranges that will be used most frequently, and whether in continuous or only occasional duty.

Continuous Duty means normal use all day, such as in production testing, where tests may be made every few seconds.

Table IV
SELECTION CHART
OF
POWER SUPPLIES FOR DUCTER LOW RESISTANCE OHMMETERS

DUCTER OHMMETER			BATTERY KIT				Rectifier and Battery Charger	RECTIFIER ONLY
CAT.	RANGES	NOMINAL TESTING AMPS.	CAT. 733-E 2 Cat. 4FH Burgess Dry Cells	CAT. 735-E 1 Cat. B4 Edison Cell	CAT. 736-E 2 Cat. B4 Edison Cells	CAT. 737-E 3 Cat. B4 Edison Cells	CAT.* 738 15 Amps.	CAT.* 739-B 10 and 100 Amps.
713	1.00 ohm .100 ohm .0100 ohm	1	Cont.	Cont.	Cont.	Cont.	Cont.	Cont.
	.00100 ohm	10	Occ.	Cont.	Cont.	Cont.	Cont.	Cont.
	.000100 ohm	100	*Do not use.*	*Do not use.*	Occ.	Cont.	*Do not use.*	Cont.
714	1.00 ohm .100 ohm .0100 ohm	1	Cont.	Cont.			Cont.	
	.00100 ohm	10	Occ.	Cont.			Cont.	
718	5.00 ohm	0.15	Cont.	Cont.			Cont.	
	.500 ohm .0500 ohm	1	Cont.	Cont.			Cont.	
	.00500 ohm	2	Cont.	Cont.			Cont.	
	.000500 ohm	15	Occ.	Cont.			Cont.	

Cont. = Continuous Duty Occ. = Occasional Duty * 50° C Ambient

Occasional duty means any application other than production—such as laboratory measurements and occasional tests on equipment in service.

See Bulletin 24-25, 1954 edition, for further description and specifications of Battery and Rectifier Power Supply Sets for Ducter Instruments.

USE OF BATTERY POWER SUPPLY KITS

These are connected to the Ducter instrument as per Figs. 9 and 13, using leads provided for that purpose. Use the respective kits only for the instrument ranges shown in Table IV.

When using the 0 to 100-microhm range of Cat. 713 Ducter instrument (which requires 100 amperes), see item 4, page 22.

Cells or batteries are always connected in parallel, *never* in series.

Cat. 733-E Battery Kit contains 2 Cat. 720 4FH Burgess dry cells. When these become low or exhausted, replace with new ones.

Cat. 735-E, 736-E and 737-E Battery Kits contain nickel-iron-alkaline cells of types indicated in Table IV.

Should you have occasion to make up your own battery power supply, be sure to observe the limitations for resistance of current leads as stipulated in the last column in Table I, page 4, and as described under *Current Lead Resistances,* page 16.

After connecting the battery and test leads to the instrument, touch together the C points of the test leads. The pointer should move *promptly* to zero, indicating that the battery has been properly connected and is in good condition.

Indication of Weak Battery

A weak or partially discharged battery may be identified by a sluggish movement of the instrument pointer when the two current test leads C and C are touched together. This assumes normal current test lead resistance. Should the pointer happen to be floating close to Zero when you are about to make this test, move the instrument sidewise so as to deflect the pointer and then touch together the C and C leads.

A weak battery is similarly indicated by sluggish pointer response when making measurements.

TABLE V

EDISON CELL DATA USING CATALOG 739-B POWER SUPPLY AS CHARGER

Battery Kit Cat. No.	Edison Cell	Rated Amps.	Avg. Volts	Rated Amp. Hrs.	Discharged Volts	Charger Setting	Approx. Charge Rate**	Time Hours	Charge Amp. Hours	Max. Permissible Electrolyte Temp.	Pounds Renewal Solution per Cell
737-E	B-4 3 in par.	45	1.2	225	.9	High Low	90 35	2 3	180 105	115° F 115° F	1.94
736-E	B-4 2 in par.	30	1.2	150	.9	Low	30	6	180	115° F	1.94

EDISON CELL DATA USING CATALOG 738 POWER SUPPLY AS CHARGER

735-E	B-4 one cell	15	1.2	75	.9	One rate only avail.	15	6	90	115° F	1.94

** This rate may vary ± 15%.

FIGURE 15. Cat. 735-E, Battery Kit, with 1 Cat. 726 B4 Edison cell.

FIGURE 16. Cat. 737-E, Battery Kit, with 3 Cat. 726 B4 Edison cells.

Charging

The complete charge in ampere-hours should be achieved in 6 to 7 hours at normal rate. However, booster rates may be used for short periods as indicated in Table V which is made up for use of Cat. 738 and Cat. 739-B Rectifier Power Supplies as chargers.

Low-rate charging has no permanent effect on Edison Cells, nor has it any very appreciable immediate effect where the discharge is also at a low rate. However, when it is desired to discharge continuously at normal rates or above, low rate charging may cause loss of capacity. This is due to the fact that low rates will not completely reduce the iron or negative electrode, or in other words, completely charge the battery. Therefore, it is suggested that normal-rate charging, either on the constant-current or the average-normal basis, is best in cases where full battery capacity is required before recharging.

A cell may be considered to be fully charged when the voltage ceases to increase during a half-hour period with constant current flowing.

When an Edison Battery does not give satisfactory capacity on discharge at rates several times normal, it is considered sluggish. This sluggishness or low capacity may result from persistent low-rate discharging, frequent low-rate charging, long stands, seldom discharging completely, or from weak solution. With the exception of the last named, the primary cause is lack of work. Edison Batteries thrive on work. To restore sluggish cells, completely discharge them at normal rates to zero, and then place the cell on short-circuit for two hours.

Follow this by an overcharge. If sluggishness persists the cycle should be repeated. In the worst cases, satisfactory results can usually be obtained by several such cycles.

If cells are to be charged by the taper current method, the manufacturer's instructions should be consulted.

Inspection

Edison Batteries are all thoroughly formed at the factory, after which they are shipped in either a charged or discharged condition.

A red label, included with the battery in each shipment, indicates that the cells are charged ready for immediate use.

Upon receipt of the battery, inspect each cell for solution height. Use the glass tube furnished for this purpose. Do not use a match or other open flame for inspection.

Electrolyte has been spilled if the tubes are visible above the surface of the liquid, or if the inside of packing case shows yellowish stains. The loss must be replaced, preferably with Edison Storage Battery "Standard Refill Solution," or lacking this, with "Standard Renewal Solution." The proper height of solution for each type of cell is ½".

When the level of solution is only a small amount below the proper height, fill with distilled water, and in the future use distilled water for replenishing the solution.

Carefully remove from the exposed poles any grease or dirt.

The positive pole of an Edison Cell is designated by a red bushing around the pole and plus (+) stamped on the cell cover.

The negative pole is designated by a black bushing around the pole; no designating mark is on the cover.

A loose or dirty contact on a cell pole will cause excessive heating, and may be detected by feeling the connectors during service conditions.

To disconnect cable lugs, first remove nut from each pole. A disconnecting jack is shipped with each battery. This jack is designed to straddle the pole and engage the lug, thereby removing it by screw-jack action.

Caution

Never put lead battery acid into an Edison Battery, or use utensils that have been used with acid.

Never bring a lighted match or other flame near a battery.

Never lay a tool or any piece of metal on a battery.

Always keep the filler caps closed except when necessary to have them open for filling.

Keep batteries clean and dry externally.

Edison electrolyte is injurious to the skin or clothing and must be handled carefully. Solution spilled on the person should be immediately washed away with plenty of water.

Use of Cat. 738 and Cat. 739-B Rectifier Power Supplies as Chargers

Cat. 738 will charge one B-4 Edison Cell at charging rates shown in Table V. Cat. 739-B will charge three parallel connected B-4 Edison Cells or two parallel connected B-4 Edison Cells at charging rates shown in Table V.

Connect the charger, by means of its supply cord, to a 115 volt 60 cycle outlet. Make connections from charger binding posts, + to + and — to —, to cell or cells to be charged. Use the leads provided. If other leads are to be used, their combined resistance should not exceed approximately .0015 ohm. Turn on the switch; green light indicates the charger is in operation. See Section VI concerning thermal protection and ventilation.

Cat. 738 is rated at 20 amperes continuous. Cat. 739-B is rated at 40 amperes continuous on the low setting and 100 amperes continuous on the high setting. Charging rates should preferably not exceed these values for continuous duty.

NOTES

NOTES

Section VI

RECTIFIER POWER SUPPLIES

Some applications of the Ducter instrument are more conveniently conducted with a portable rectifier type of power supply, that can be plugged into a lighting circuit, than with a battery.

Your choice between a battery and a rectifier power supply will depend on: (a) which is most simple and practicable for the application, (b) whether tests are to be made near or away from an a-c outlet, and (c) whether charging equipment is available, in case a storage battery is indicated or preferred

The first cost of a battery is less than that of a rectifier, but the service-free features of the latter may justify it.

The following Rectifier Power Supplies have been specially designed for use with Ducter instruments. They are of the selenium dry rectifier type and are equipped with supply cords for connecting to 115 volt, 60 cycle, a-c circuits, and with flexible insulated cables 3 ft. long for connecting to the Ducter instrument. If other connecting leads are used, be sure to observe the limitations for resistance of current leads as stipulated in the last column in Table I, page 4, and as described under Current Lead Resistances, page 16.

These rectifier power supplies must be used within the limitations given in Table IV, page 38, and it is strongly recommended that they be used in preference to any other type of rectifier power supply which may be available.

Connecting and Operating

Rectifier power supplies are connected as shown in Figs. 9 and 13. Avoid using the units in higher-than-rated ambient temperatures. If the rectifier temperature reaches its maximum permissible value, a thermal cut-out will de-energize both the set and its green pilot light. In such event its use must be discontinued until the rectifier cools.

FIGURE 17. Cat. 738, Portable Rectifier Power Supply and Battery Charger.

FIGURE 18. Cat. 739-B, Portable Rectifier Power Supply, for continuous duty at 50°C.

Use of Cat. 738 Rectifier Power Supply to Operate Ducters

Cat. 738 has a 20 ampere continuous output rating at one volt d-c. It may be used for direct operation of Ducter instru-

ments as per Table IV, page 38. The a-c input at 15 amperes for Ducter applications is approximately 50 volt-amperes.

Do not attempt to use this rectifier for the 0 to 100-microhm, 1.00 ampere range of the Cat. 713 Ducter instrument.

This rectifier is also designed for charging Edison Cells used in Battery Kits as shown in Table V, page 40 and as described on page 43.

Use of Cat. 739-B Rectifier Power Supply to Operate Ducters

This rectifier is specially designed for use with Cat. 713 Ducter instruments as shown in Table IV, page 38. It has two continuous d-c output ratings at one volt d-c; (a) 10 amperes continuous, and (b) 100 amperes continuous as rated. The a-c input for 10 ampere output is about 25 volt-amperes and for the 100-ampere output is about 370 volt-amperes.

The 10 ampere rating is used for the first four Cat. 713 Ducter ranges —0 to 1.00 ohm, down to 1000 microhms. The 100 ampere rating is used for the lowest range —0 to 100 microhms.

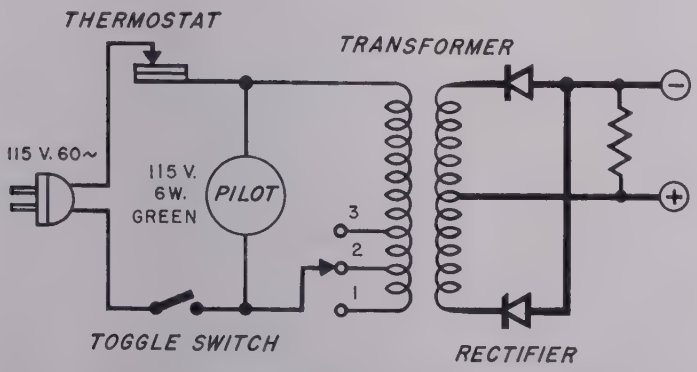


FIGURE 19. Schematic wiring diagram of the Cat. 738 Rectifier Power Supply and Battery Charger.

This fan-cooled rectifier may be used continuously on its 100-ampere rating in 50° C ambient.

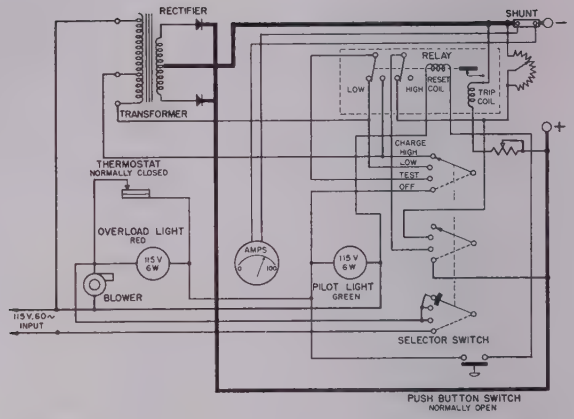


FIGURE 20. Schematic wiring diagram of the Cat. 739-B Power Supply (Earlier models omit the rotary "Charge High-Charge Lo" Switch which diagram also applied to Cat. 739, an early model without blower.)

Ventilation

Although fan cooled this rectifier should be used in well-ventilated and shaded locations to prevent undesirable operation of the protective thermal cut-out.

Inductive Test Specimen

Should the high rating be in use and the test specimen be highly inductive, a higher-than-normal voltage may appear at the terminals of the rectifier when the thermal switch opens. This will trip the latching relay, and transfer the supply to the 10-ampere rating, thereby making it operative only at 1 or 10-amperes. In this event the operator should press the reset button, returning the supply to the 100-ampere rating, after waiting the required time for the thermal switch to close.

Thermal Protection

A thermal cut-out feature is provided, as mentioned above. Action of this cut-out is indicated—on the 100-ampere rating—by a red pilot light. When this occurs the OFF-ON toggle switch should be returned to the OFF position and the rectifier be allowed to cool. When the rectifier has cooled sufficiently, the green pilot lamp will re-light when the toggle switch is returned to the ON position.

Section VII

PRINCIPLE OF OPERATION OF THE "DUCTER" LOW RESISTANCE OHMMETER

The well-known d-c fall-of-potential method of measurement is employed in the "Ducter" Low Resistance Ohmmeter; but instead of using separate current and voltage measuring instruments, the result is indicated directly by a cross-coil true Ohmmeter.

As shown in Fig. 21, the moving system of the Ohmmeter consists of two coils mounted rigidly together on a common axis in the field of a permanent magnet. There are no control springs as in an ammeter or voltmeter. Instead, current is led to the ohmmeter coils by flexible conducting ligaments which exert only slight torque, so that when the Instrument is approximately level, and with nothing connected, the pointer will float towards zero.

Current in the current coil is proportional to that through the resistance under test and tends to move the pointer to zero on the scale. This coil is the control coil and its action is similar to that of a restraining spring.

Current in the potential coil is proportional to the voltage drop between the potential contact-points across the resistance under test, and tends to move the pointer to the top of the scale. This coil is the deflecting coil. The final position of pointer is therefore dependent upon the balancing of the opposing forces exerted by these two coils and the scale is marked directly in ohms or fractions of an ohm.

The true Ohmmeter of the "Ducter" Instrument is independent of the exact voltage of the supply used for the test, because any reasonable change in the supply voltage affects both Ohmmeter coils in the same proportion. The pointer, therefore, remains in the same position for a given resistance under test, and no rheostat or other current-regulating device is necessary.

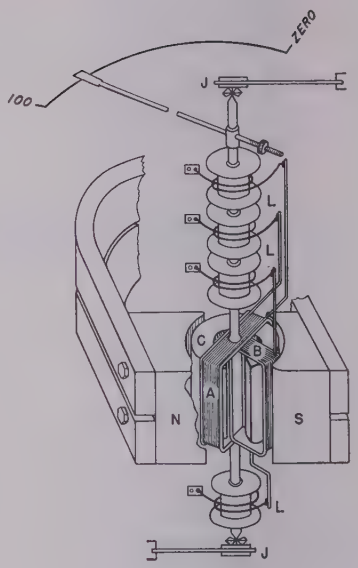


FIGURE 21. Showing diagrammatically the moving system and magnetic structure of the "Megger" true ohmmeter.

A =potential or deflecting coil

B =current or control coil

LLL =ligaments hung loosely around insulating spools

JJ =spring-supported jewel bearings

NS =permanent magnet

C =C-shaped iron core mounted in a fixed position coaxially with the moving system

The supply voltage can even change while a test is being made and there will be no movement of the pointer, unless the circuit under test happens to be highly inductive. The current for any range is limited to a safe amount by resistances in the Instrument. This holds true for supply voltages up to 1.5 volts.

The "Ducter" Instrument is compensated for ordinary temperature changes in all of its ranges.

This applies only to the Instrument itself, and not to the resistance under test. See Section IX.

Calibration—Accuracy

Ducter instruments are accurate in normal hard service to *within* 1% of full scale deflection at all points on the scale. Any check for accuracy should be made at normal voltage and current as per Table I, page 4.

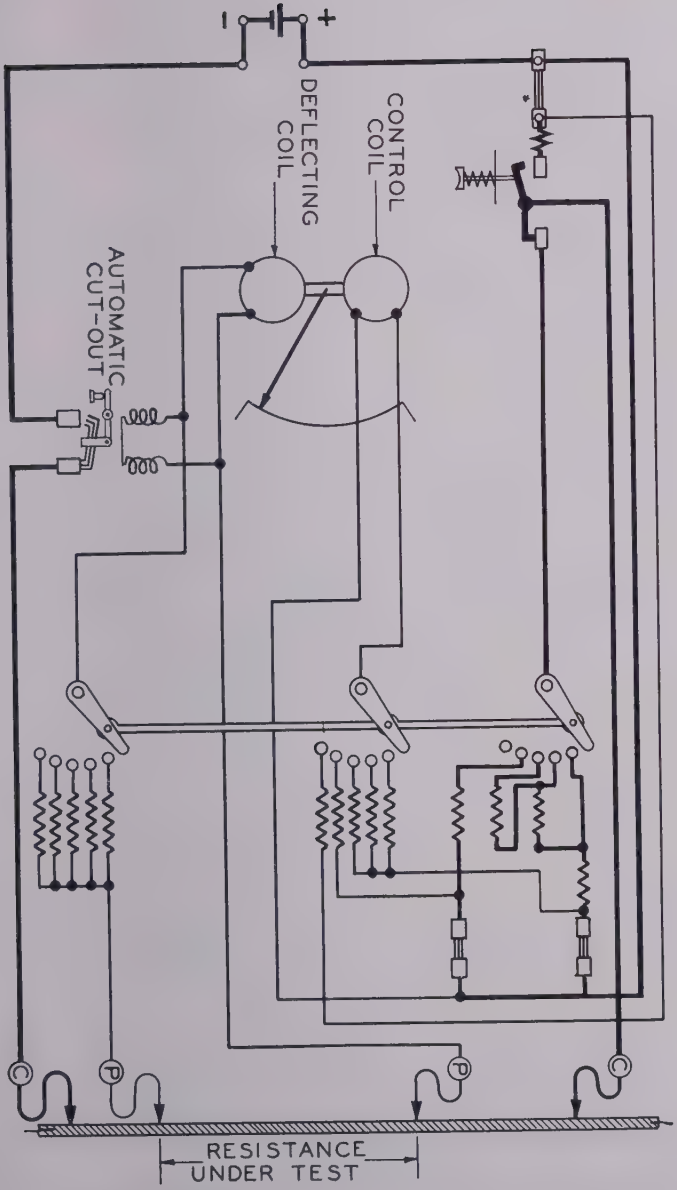


FIGURE 22. Schematic circuit diagram for Cat. 713 "Ducter" Low Resistance Ohmmeter.

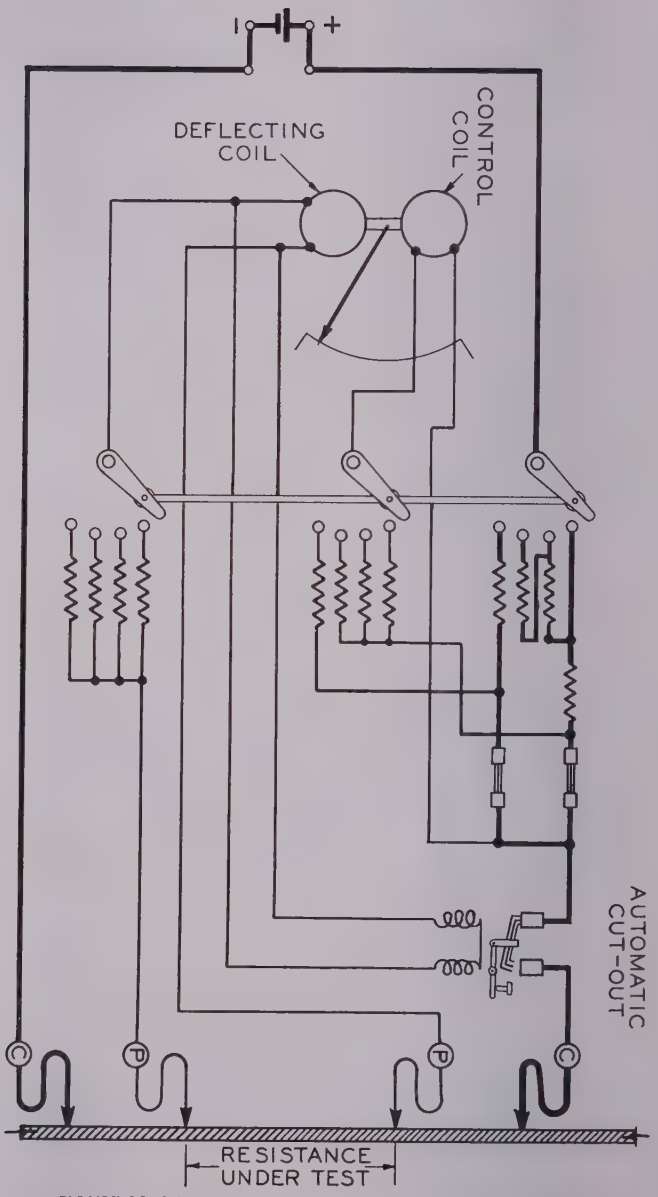


FIGURE 23. Schematic circuit diagram for Cat. 714 "Ducter" Low Resistance Ohmmeter.

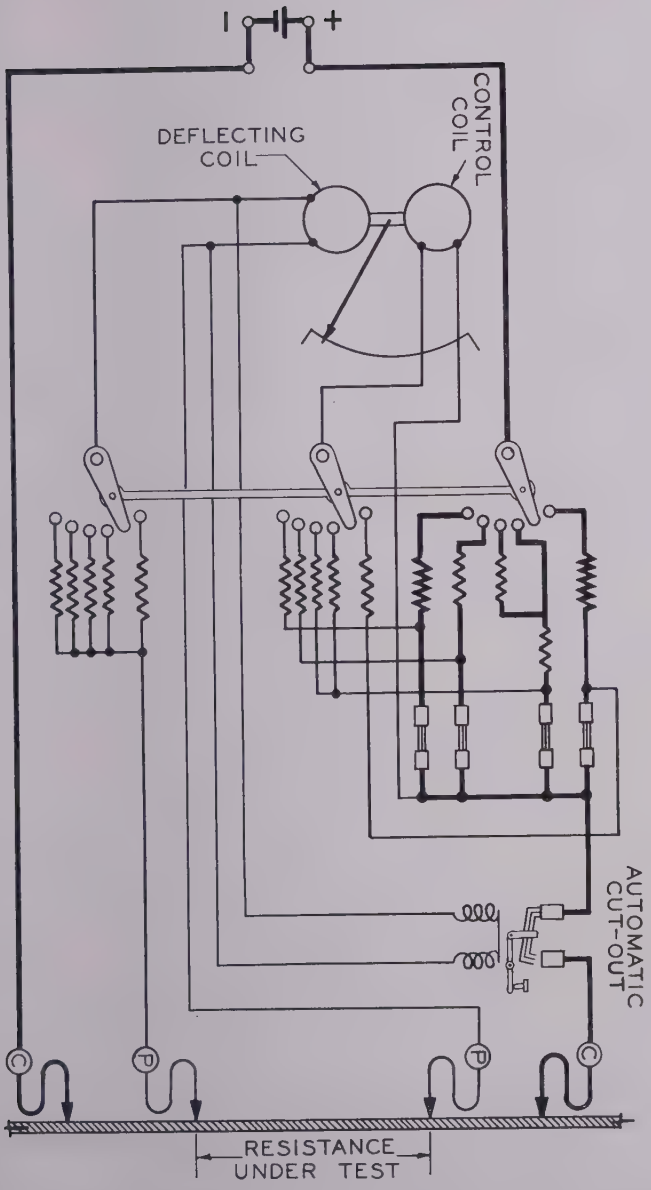


FIGURE 24. Schematic circuit diagram for Cat. 718 "Ducter" Low Resistance Ohmmeter.

NOTES

Section VIII

RESISTANCE NETWORK DATA

The following passive resistance networks are those which may be encountered in simple circuits, and such equipment as multi-conductor cables, three-phase transformers, and a-c generator armatures.

The Series Network:

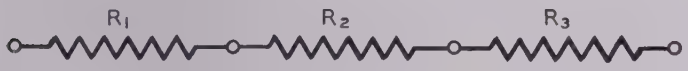


FIGURE 25.

$$\text{Total } R = R_1 + R_2 + R_3 + \ldots\ldots\ldots\ldots R_n$$

The Parallel Network:

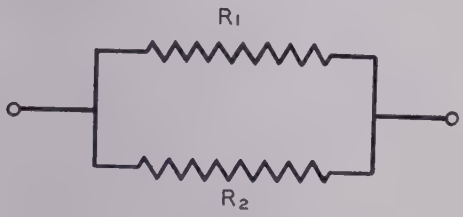


FIGURE 26.

$$\text{Total } R \text{ for two paths} = \frac{R_1 R_2}{R_1 + R_2}$$

$$\text{Total } R \text{ for three paths} = \frac{R_1 R_2 R_3}{R_1 R_2 + R_2 R_3 + R_3 R_1}$$

$$\text{Total } R \text{ generalized} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots\cdots \frac{1}{R_n}}$$

The Star Network:

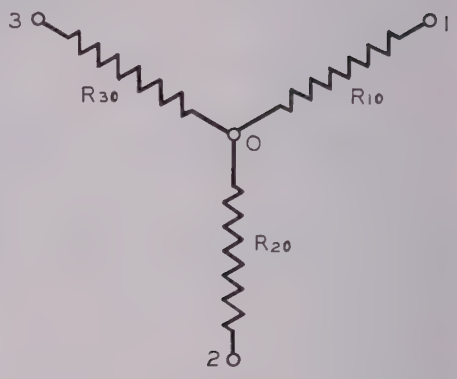


FIGURE 27.

$$R_{10} = \frac{R_{12} - R_{23} + R_{31}}{2}$$

$$R_{20} = \frac{R_{12} + R_{23} - R_{31}}{2}$$

$$R_{30} = \frac{R_{31} - R_{12} + R_{23}}{2}$$

The Delta Network:

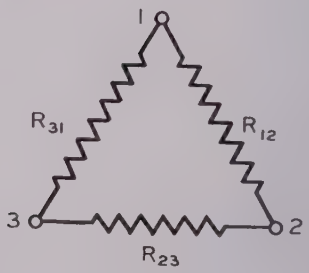


FIGURE 28.

$M =$ Measurement between two terminals of a closed delta network.

$$N = \text{Numerator}$$
$$= 2M_{12}M_{23} + 2M_{23}M_{31} + 2M_{31}M_{12} - [(M_{12})^2 + (M_{23})^2 + (M_{31})^2].$$

$$M_{12} = \frac{R_{12}(R_{23} + R_{31})}{R_{12} + R_{23} + R_{31}} \qquad R_{12} = \frac{N}{2M_{31} + 2M_{23} - 2M_{12}}$$

$$M_{23} = \frac{R_{23}(R_{12} + R_{31})}{R_{12} + R_{23} + R_{31}} \qquad R_{23} = \frac{N}{2M_{31} + 2M_{12} - 2M_{23}}$$

$$M_{31} = \frac{R_{31}(R_{12} + R_{23})}{R_{12} + R_{23} + R_{31}} \qquad R_{31} = \frac{N}{2M_{12} + 2M_{23} - 2M_{31}}$$

It is sometimes desirable to check the resistance of a complete delta network that cannot readily be opened, such as the delta winding in a three-phase power transformer, or a three-phase generator or motor armature. In such cases, M_{12}, M_{23}, and M_{31} should be equal if R_{12}, R_{23}, and R_{31} are equal. If not, the individual legs of the delta network may be unbalanced.

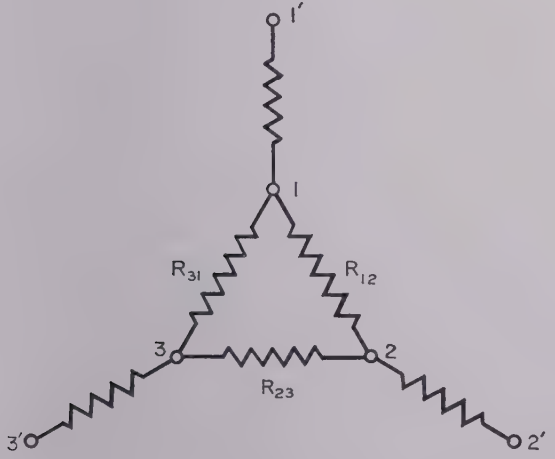


FIGURE 29.

Fig. 29 shows such a network including cable resistances from each delta point to the terminals of the apparatus under test. If the three points of the delta are accessible then the values of the three individual leg resistances, R_{12}, R_{23}, and R_{31}, may be calculated from data obtained by making a "Ducter" Instrument test as shown in Fig. 30.

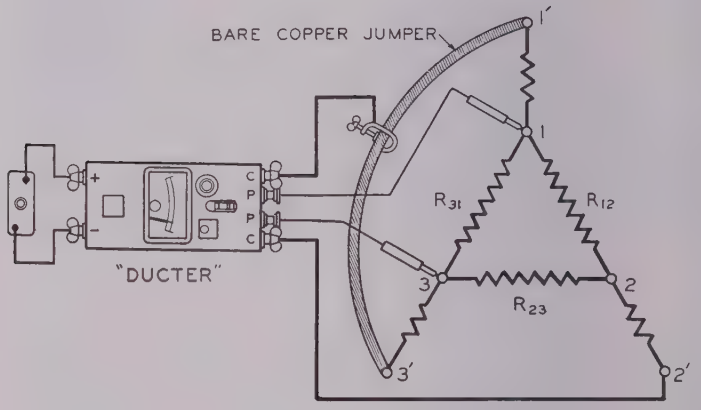


FIGURE 30.

The test data necessary to make the calculations are obtained as follows:

First, measure the resistance R_{12} and R_{23} in parallel. This is done by short-circuiting R_{31} with a bare, low resistance, copper jumper, and connecting one of the current terminals of the "Ducter" Instrument to the 2′ point of the delta, and the other current terminal to the jumper at a point midway between 1′ and 3′ points of the delta.

Apply the potential prods to the 1 and 3 points of the delta and slide the current connection on the jumper until a zero reading is obtained. Use the lowest range of the "Ducter" Instrument to obtain this zero balance.

The potential prods are then applied to the 2 and 3 points, or the 1 and 2 points, of the delta, and the parallel resistance of R_{12} and R_{23} measured.

The foregoing procedure is then repeated for the other two sides of the delta. Make sure that the potential prods are applied to the points of the delta in each case, and not to the extensions of these points.

Let:

M_{123} = the resistance of R_{12} and R_{13} in parallel
M_{231} = the resistance of R_{23} and R_{31} in parallel
M_{312} = the resistance of R_{12} and R_{31} in parallel

Then:

$$R_{31} = \frac{2\,(M_{123}\,M_{231}\,M_{312})}{M_{123}\,M_{231} + M_{231}\,M_{312} - M_{123}\,M_{312}}$$

$$R_{23} = \frac{2\,(M_{123}\,M_{231}\,M_{312})}{M_{123}\,M_{312} + M_{123}\,M_{231} - M_{231}\,M_{312}}$$

$$R_{12} = \frac{2\,(M_{123}\,M_{231}\,M_{312})}{M_{123}\,M_{312} - M_{123}\,M_{231} + M_{231}\,M_{312}}$$

NOTES

Section IX

TEMPERATURE DATA

Resistance Values Corrected for Temperature

When making accurate comparisons of resistances under test their temperatures must be considered, since the resistances of all metals are greatly affected by temperature. Where accuracy is important the most practical method is to measure the temperature of the resistance under test, and determine by calculation the resistance at the temperature desired. The mathematical formula for 100% conductivity copper is:

$$R_1 = R_2 \frac{T_1 + 234.5}{T_2 + 234.5}$$

where—

R_1 = Resistance at desired temperature T_1.
R_2 = Resistance measured at time of test.
T_1 = Temperature in degrees C at R_1.
T_2 = Temperature in degrees C at time of test.

Determining Temperature from Resistance Measurements

Very often the most practical means of determining the average temperature of electrical equipment is to measure the resistance of certain conductors within the equipment, and calculate the average temperature when the conductor resistance at a known temperature has been first established. This is often done to determine the temperature of armatures and fields in rotating equipment, the temperature of cables, and the temperature of transformer windings. See Technical Bulletin No. 21T4, pages 11 and 12.

The mathematical formula for this calculation is:

$$T_2 = \frac{R_2}{R_1}(234.5 + T_1) - 234.5$$

Where—

T_2 = Temperature in degrees C desired at time of test.

T_1 = Known temperature in degrees C at R_1.

R_1 = Resistance at known temperature T_1.

R_2 = Resistance measured at time of test.

R_1 should be determined at such time as the equipment has been idle under constant ambient temperature condition for a time sufficiently long to be sure that T_1 is the same as the ambient temperature. This information might be obtained from the manufacturer of the apparatus, or from the original factory test report. Of course, it must be remembered that conditions such as defective joints or contacts may affect the total resistance at the same temperature.

Since the Wheatstone bridge is not particularly accurate for measuring resistances below one ohm, and since most large electrical equipment have winding and conductor resistances much lower, the "Ducter" Low Resistance Ohmmeter is often used for resistance measurements of this kind.

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